Bedforms and Mine Burial

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LONG-TERM GOAL

The goal of this work is to develop a predictive understanding of coastal bedforms and their effect on the burial of objects on the seafloor.

OBJECTIVES

The objective of the research is to develop a robust characterization of the growth of the bottom profile envelope (the range from minimum to maximum depth) in the nearshore, both in time and space, using existing data. The specific objectives are to

- investigate the time evolution of the bottom profile envelope
- quantify the probability of burial
- develop a model for prediction of bed profile statistics and mine burial

APPROACH

The generation and migration of bedforms (eg, ripples, megaripples and sand bars) on sandy bottoms in the nearshore (0-8 m water depths) provides a mechanism for objects on the seafloor to become buried. As a bedform migrates past a mine, the mine will fall to the low point of the bedform trough before subsequently being buried by the passage of the following bedform crest. The statistics of mine burial by bedforms can be determined by the statistics of bed elevation changes and the time evolution of the bottom profile envelope. Existing data sets are being used to examine the bed profile envelope.

We define the bottom profile as $h(x, \tau)$, and the profile envelope as spanning from $h_{min}(x, \tau)$ to $h_{max}(x, \tau)$. The envelope has zero thickness at τ=0 (eg, when mines are placed) and as bed features form and

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migrate the thickness of the envelope grows with time. Maximum bed envelope thickness, $D_{max,}$ at the end of set time windows is calculated (Fig 1) and the mean maximum envelope thickness is examined as a function of time (Figs 2 and 3). In addition to the growth and statistics of the profile envelope, measurements of overlying wave and currents (when available) are being used to investigate relationships between the bed envelope and the measured flow parameters (Fig 4).

When D_{max} exceeds W, the vertical scale of a mine, the mine can be buried. However, at any subsequent time, burial depends on the instantaneous elevation above envelope minimum, $D = h - h_{min}$. In other words, a mine that is buried by a bedform crest can be exposed in the following trough of a migrating bedform. Thus, the likelihood of burial after a set amount of time is being examined (Fig 5).

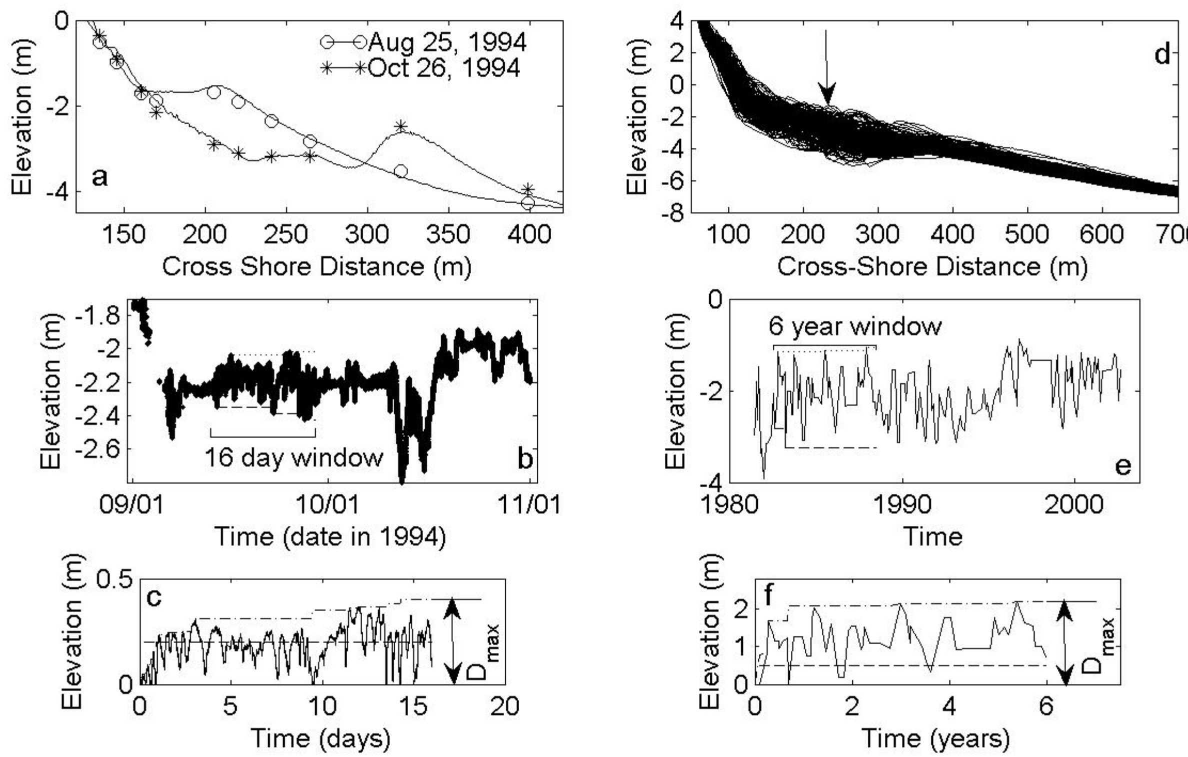

Figure 1 a) Cross-shore profiles (solid lines) and altimeter array (symbols) deployed during Duck94. b) Elevation versus time (solid line) measured with the sonar altimeter at x=170 m in a). The dotted and dashed lines are minimum and maximum depths for a representative 16-day period. c) The dashdot line is the bed profile envelope, D_{env} (the difference between dashed and dotted lines in b) plotted versus time. The solid line is the instantaneous elevation above envelope minimum, D (solid line minus dashed line in b). The dashed line is an example elevation threshold, W, eg the height of a mine. d) Cross-shore profiles 1981 through 2002. e) Time series of bed elevation at X = 225 m in d) sampled from approximately monthly profiles. Elevation in profiles is averaged over 20 m (eg, X=215-235m is averaged to give one point at X=225 m). The dashed and dotted lines represent the maximum and minimum depths reached during a representative 6-year period. f) The bed profile envelope, D_{env} (the difference between dashed and dotted lines in e), plotted versus time (dashdot). The solid line is the instantaneous elevation above envelope minimum, D (solid line minus dashed line in e). The dashed line is an example elevation threshold, W.

In addition to temporal likelihood of burial, the spatial distribution of bedforms and resulting spatial likelihood of burial will be examined. For example, Gallagher et al. (2003) have found that, although bedforms are ubiquitous in shallow water (depth < 4 m), their spatial distribution is patchy. The spatial patterns of bedforms (bedform shape, megaripple patches, bar/trough/rip morphology, etc.) become important in determining the fraction of bed area for which $D < W$.

WORK COMPLETED

The maximum bottom profile envelope thickness, D_{max}, has been examined using data from Duck94 (Fig 1a,b,c). Early results have suggested that Duck94 was not long enough to characterize envelope growth completely (Fig 2), so longer time series of bed level fluctuation (Fig 1 d,e,f) are now being used to extend the statistics of bed envelope growth to include longer time-scale morphological changes (Fig 3).

D_{max} depends on mean normalized significant wave height, $H_{sig\text{-}norm}$ (measured in 8 m depth, normalized by the water depth at the sensor and averaged over the envelope's time window). The slopes of the best-fit line between $H_{sig\text{-}norm}$ and D_{max} are calculated and shown to change as a function of window length (Fig 4).

To investigate the likelihood of burial of an object, the instantaneous elevation of the bed above envelope minimum, D, at the end of the set time windows is compared to a threshold elevation W (the vertical scale of a mine, here 20 cm is used as an example, dotted line in Fig 1c). If $D>W$ then an object is buried and if $D<W$ then an object is exposed. Time windows are moved in 1 hr increments, thus hourly measures of "buried/not buried after X days" are obtained. Percent burial, P, is calculated as the number of buried observations divided by the total number of observations (Fig 5).

Results from the study of bed profile envelope characterization are discussed below and a manuscript describing that work is being prepared for publication in the Mine Burial Special Issue of Journal of Oceanic Engineering.

RESULTS

Using the Duck94 data (2-mo experiment, 11 altimeters in 1.5-5 m water depth), D_{max} was calculated for 4- to 16-day windows with 50% overlap (Fig 1). A typical histogram of D_{max} for the 6-day window (Fig 2a) has a peak at about 30 cm. This is in agreement with observations of megaripples, which have heights of 10-50 cm. The second small peak between 60 and 80 cm corresponds to larger-scale morphology changes. Observed mean and standard deviation of D_{max} for each window are shown in Fig 2b. The large standard deviations are the result of using all observations for the two month period including both megaripples and larger-scale changes as well as shallow and deep sensors.

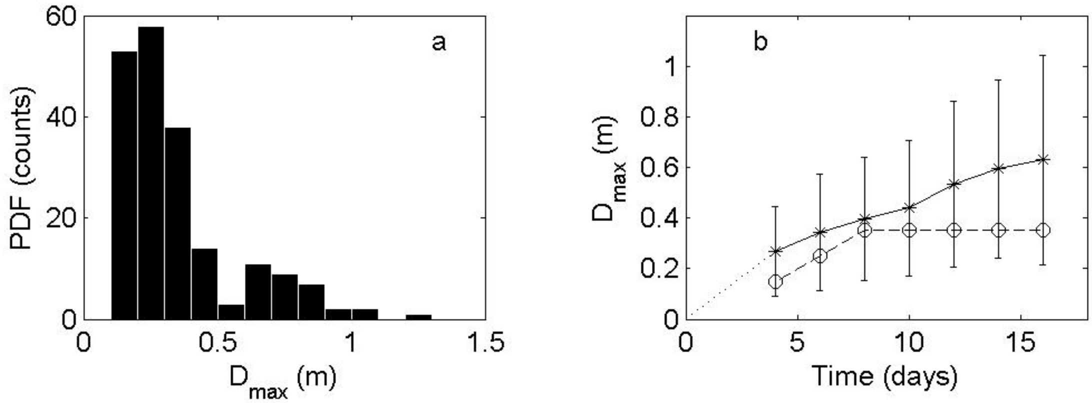

Figure 2. a) Histogram of D_{max} for 6-day window. Two months of data were used (Fig 1b), with τ=0 starting every 3 days (50% window overlap) giving 19 estimates for each of 11 sensors. b) Mean and standard deviation of D_{max} are plotted versus time (asterisks) [increasing monotonically from about 25 cm at 4 days to 62 cm at 16 days]. The circles are the peak values from the histograms plotted versus time [increasing monotonically to about 35 cm after 8 days and leveling off].

It was proposed as part of this study that D_{max} would increase with time following an exponential taper (increase quickly at first and then taper off to a maximum or asymptotic value). D_{max} does increase with time (Fig 2b) but the exponential trend is not observed in the mean D_{max} values (asterisks). If the peak of the histogram is used as a representative value, the exponential taper is observed (circles, Fig2b). The peak in the histograms is associated with megaripples and the growth of megaripples is seen to increase to a maximum of 30 cm after 8 days. However, the mean D_{max}, including all scales of bed morphology change does not follow an exponential taper after only 16 days.

Longer time series are being examined for envelope growth, including bipod data from Duck (5 yrs), FRF CRAB survey data (20 yrs), Egmond survey data (40 yrs), and Danish coastal surveys (~60 yrs ?). The surveys are being sampled to generate time series of the seafloor at a single location, then the time series are being analyzed for envelope growth (eg, Fig 1d,e,f). These longer term time series are much lower resolution, with surveys done monthly, biannually or annually. However, they do allow the observations of D_{max} to be extended to much longer time periods. The predicted exponential taper is observed, but an asymtotic value of about 2.5 m is not seen for many (4-6) yrs (Fig 3).

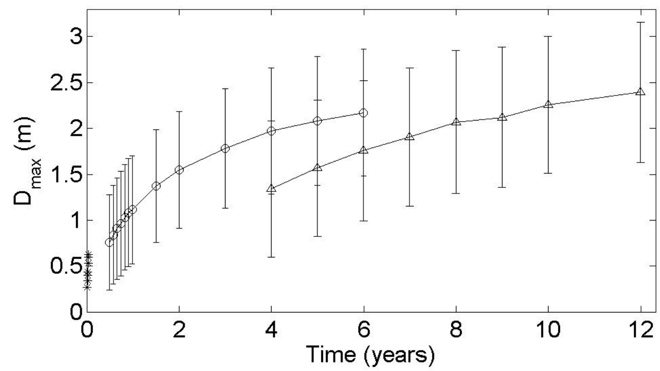

Figure 3. Mean (and standard deviation of) D_{max}, for the two long-term survey data sets (Duck-circles, Egmond-triangles) plotted versus time [Curves overlap and together increase as an exponential taper from about 0.75 m at 6 mos to about 2.5 m after 12 years]. Asterisks are mean D_{max} from the short-term altimeter data (same as asterisks in Fig 2).

D_{max} and $H_{sig\text{-}norm}$ (measured in 8 m depth, normalized by the water depth at the sensor and averaged over the envelope's time window) from Duck94 are positively correlated (Fig 4). The slopes of the best fit lines (S) between D_{max} and $H_{sig\text{-}norm}$ increases with time (window length) (diamonds, Fig 4c).

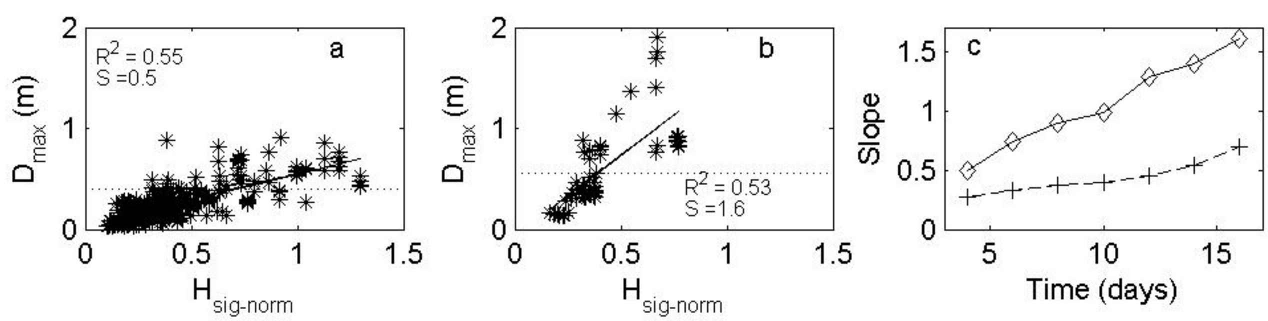

Figure 4. D_{max}, after a) 4 and b) 16 days versus $H_{sig\text{-}norm}$. [Scatter plots showing a positive correlation]. Solid lines are least squares best-fit lines to the data (asterisks) with correlation coefficient R and slope S. c)Slopes, S, of best-fit lines between D_{max} and mean $H_{sig\text{-}norm}$ (diamonds) and peak $H_{sig\text{-}norm}$ (pluses) versus time (window). [Slope increases with window length].

In Fig 4a and b, $H_{sig\text{-}norm}$ was averaged over the whole time window. Conditions that do not contribute to the envelope growth can affect $H_{sig\text{-}norm}$. For example, one large wave event during otherwise low wave conditions could generate a large envelope, but the low waves would reduce the average wave height. This effect could make S anomolously steeper for longer time windows. Normalized maximum significant wave height, $H_{max\text{-}norm}$, during the time windows was also investigated to attempt to eliminate this averaging bias (with the potential for the opposite bias). Although the correlation coefficients are lower for $H_{max\text{-}norm}$ than for $H_{sig\text{-}norm}$, the slope increase is still observed. Further investigation of this effect will help elucidate a predictive relationship between waves and D_{max}. Various fluid parameters calculated from current meters co-located with the altimeters were not as well correlated with D_{max} as the offshore significant wave height.

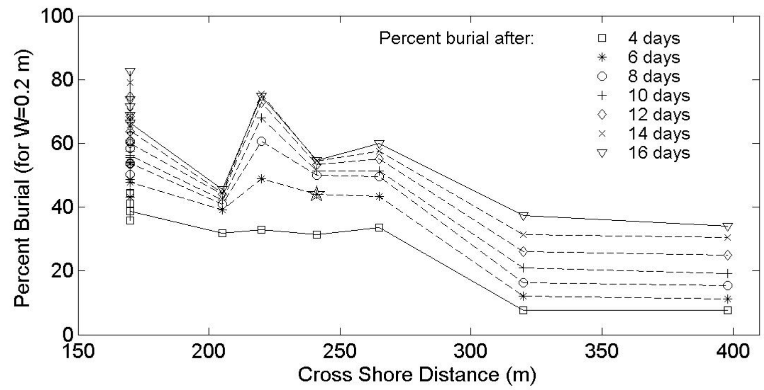

Figure 5. Percent burial versus cross-shore location and for each of the time windows. [P increases with time and increases in shallow water. In the surf zone, P=45-75% after only 8 days. Outside the surf zone, P=16% after 8 days and P=35% after 16 days.]

Percent burial, P, is calculated as the number of observations of burial after a set amount of time, divided by the total number of observations. Burial is observed when D > W at the end of highly ovelapping time windows (every hour). Thus there are hourly observations of "buried/not buried after X days". P is observed to increase with time and P is higher shallow water (Fig 5).

As waves work the sediments on the seafloor, megaripples are generated and migrate, erosion and accretion take place and both D_{max} (Figs 2b and 3) and P increase (Fig 5). In the surf zone, waves break, currents are strong, and more energy is available to move sediment than further offshore, therefore morphological processes occur more quickly. For example, at x=240 m (Fig 5) there was significant erosion/accretion owing to bar migration during Duck94, thus an object on the seafloor in this region would become more deeply buried than at x>300 m. The object would be buried almost 50% of the time after only 6 days (star in Fig 5). In deeper water, less energy reaches the seafloor and D_{max} (not shown) and P are smaller and their temporal development occurs more slowly (15% burial after 8 days and only 35% burial after 16 days). The relationships between D_{max}, P, wave energy, water depth and time are being investigated for use as predictive tools.

IMPACT/APPLICATION

The threat of mines has an enormous impact on Naval operations. Methods exist for search and identification of proud mines, but the potential existance of buried mines is of considerable concern. This work will help to describe the process of mine burial by bottom bedform movement, and will quantify the expected time scales, probabilities and depths of burial in the nearshore.

TRANSITIONS

This work has not yet lead to any transitions.

RELATED PROJECTS

This work is part of the Mine Burial Program, a coordinated effort to study all processes of mine burial including impact and scour burial.

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